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Electrical vehicle impact on distribution network power quality

Abstract: *The electrical vehicle form a huge load (and occasionally a generator as well) that is not resistive but possibly of nonlinear character. This may have an effect on distribution network power quality and possibly disturb seriously other consumers. If this is not taken care of before expansion of electrical vehicles boom, serious damage may occur.*

Streszczenie. *Ładowanie akumulatorów samochodów o napędzie elektrycznym stworzy bardzo duże obciążenie o nieliniowym charakterze, co może oddziaływać na jakość energii w sieci oraz stanowić poważnie zagrożenie dla innych odbiorców energii. Analiza tego zagadnienia przed powszechnym wprowadzaniem pojazdów o napędzi elektrycznym pozwoli uniknąć szeregu poważnych problemów w przyszłości (**Wpływ wprowadzenia pojazdów o napędzie elektrycznym na jakość energii w sieciach rozdzielczych**).*

Keywords: Power Quality, THD, rectifier, harmonic
Słowa kluczowe: Jakość energii, THD, prostownik, harmoniczne

Introduction

Demand on electrical vehicles will definitely increase in the future in order to reduce CO_2-emissions and increase the use of renewable energy as well. Fossil energy sources will peter out and gasoline will get more and more expensive before it's getting to end. If a moderate prized battery will be introduced, the amount of electrical vehicles will explode. The huge amount of electric cars includes big energy recourse and beside of charging it may be used to feed electricity in the network as well. Impacts to network power quality will be quite similar in both cases concerning harmonic but voltages drops will turn out to be voltage surges in some cases. It is possible that EN 50160 [1] limits will not always be met because of this trend.

Load size

Rectifiers can be dimensioned in different ways, but probable basics for dimensioning will be size of feeding fuse. Probably the maximum power will be utilized when charging vehicles because then the charging time will be shortest. However in many cases maximum is one phase supply with 10 A fuse. Therefore maximum charging power is 2.3 kW. If car is driven averagely 50 km a day, it needs roughly 10 kWh, which yields to four hour charging time. There are a big amount of uncertainties but assuming that 40 % of cars may be plugged between 4 pm and 10 pm to network. If, using Finland, as example this roughly yields with it's 2,12 million passenger cars to maximum power of P = 2.000 MW when assuming statistically all cars are not loaded simultaneously. Annual peak power is roughly P_m = 15.000 MW, so this can be considered as a remarkable increase. However, this peak power normally occurs in winter mornings, so the need of power plant capacity is not increased accordingly. If designed intelligently, these vehicles can be used to feed network as well. Both cases are problematic because of the character of load being not resistive but non-sinusoidal. Load represents roughly 15 % of maximum load. Hence load may be considerably higher in other countries.

Load character

It is not known yet which kind of charges will be assembled to future electrical vehicles. Here two different types are studied to find limits which can be reached [2]. Harmonics of voltage and current are shown in table 1 as well currents in table 2. Current includes a big amount of harmonic currents but is typical of semiconductor devices. Harmonics of voltages are of illustrative character only, while these figures will depend on supply network properties too [2].

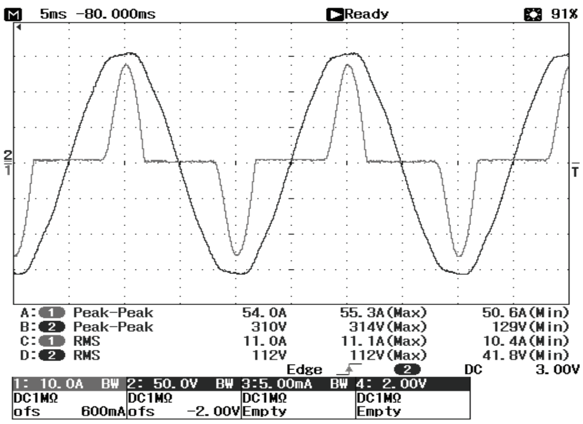

Fig. 1. Charging current of example vehicle A and corresponding voltage of supply

Table 1. Harmonics at supply voltage

u_1 [%]	u_3 [%]	u_5 [%]	u_7 [%]	u_{THD} [%]
100	2,1	1,0	0,7	2,1

Table 2. Harmonics at supply current

i_1 [%]	i_3 [%]	i_5 [%]	i_7 [%]	i_{THD} [%]
100	79,5	48,0	19,0	95,0

Other charger properties (vehicle B) are shown on figure 2.

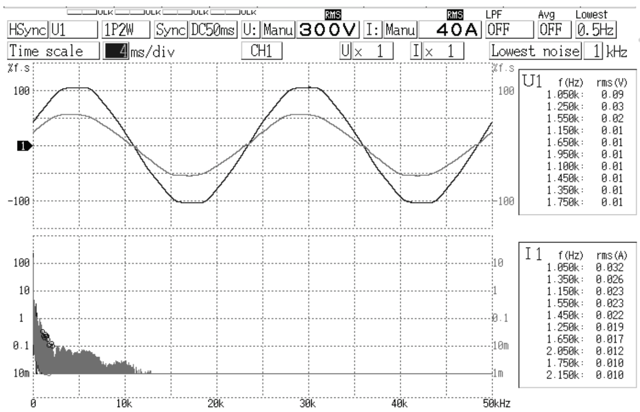

Fig.2. Charging current of example vehicle B and corresponding voltage of supply

Network harmonics

A small amount of cars to be charged do not disturb network as seen on table 1, where harmonic content is remarkably lower than accepted by standard EN 50160. But when a greater amount of chargers will be plugged impact will be bigger. Basic frequency voltage will of course have some sag as with resistive load, too. But harmonic currents will flow to network and they meet network impedance X_i (resistance neglected here). That is considered linear with frequency which yields that capacitor banks are not connected. In some cases they may cause resonances and simulation numerical values shown later might be remarkably higher. If introducing U_n = 20 kV supply with short circuit current I_k = 5 kA, we can define network impedance on secondary U_n = 400 V side to be X_{Q1} = 0,4 mΩ, S_n = 1000 kVA impedance typically has X_{T1}= 8,8 mΩ. Totally impedance on frequency f_1 = 50 Hz can be considered to be X_1 = 9,2mΩ. A simulation of load degree of 50 % is studied with results shown in table 3.

Table 3. Harmonics at transformer secondary

i	I_i [A]	X_i [mΩ]	U_i [V]
1	721,7	9,2	6,6
3	685,6	27,6	18,9
5	346,4	46,0	15,9
7	137,1	64,0	8,8

This will cause total harmonic content

(1) $$U_{THD} = \frac{\sqrt{\sum_{i=2}^{\infty} U_i^2}}{U_1}$$

which gives U_{THD} = 11, 4 %, that is far too high comparing to standard EN 50160, where THD is defined to be at maximum 8,0 %. Individual values at f_3 = 150 Hz and f_5 = 250 Hz values are too high even the load is only 50 % of transformer's nominal value. Percentages are shown in Table 4. High amount of third harmonic caused a big circulating current in Dy-coupled transformer's windings and additional warming [3].

Table 4.Harmonics at transformer secondary

i	U_i [V]	U_i [%]	U_{ENi} [%]
1	6,6	2,9	-
3	18,9	8,2	3,0
5	15,9	6,9	6,0
7	8,8	3,8	5,0

Effects on voltage distortions are presented in picture 3, where transformer secondary voltage at half load is presented.

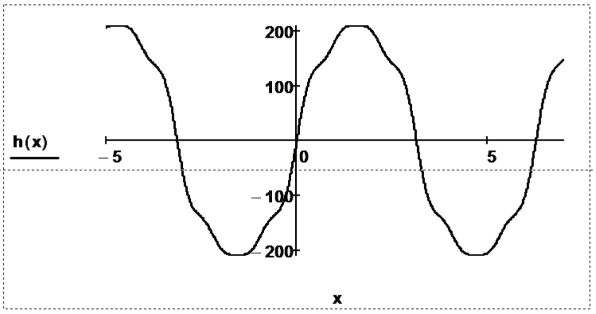

Fig.3. MathCadvoltage presentation of simulated values for 50 % loading of transformer with nonlinear load

These values are too high to be accepted. Therefore maximum loading of transformer could roughly be 30 % of nominal and that would cause quite high harmonic content, too.

Transformer loading

Beyond harmonic content loading of network component is essential too. Using semiconductor loads nominal loading can't be reached, but it is lower. Transformer loading can be approximated as well [3]:

(2) $$\frac{I_1}{I_n} \leq \sqrt{\frac{1+a_1}{[\sum_{n=1}(\frac{I_n}{I_1})^2 + a_1 \sum_{n=1} n^q (\frac{I_n}{I_1})^2]}}$$

Constant "a" stands for skin effect and "q" for corresponding increase of resistance. Constant "a" values are known to some degree, but values for "q" are unluckily not generally available. Hence use of this formula is not exact, but it gives some approximations. This normally yields that the active power of transformer nominal may be at highest roughly 75 %. This means that network component will be higher and life-cycle of them shorter.

Financial value of these effects is not easy to define, but it is not negligible. However, transformer secondary power quality begin to be at standard maximum roughly at 30 % loading supposing no other nonlinear load is coupled simultaneously. Even this may lead to problems for other users.

These problems can be solved to some degree by harmonic filtering, but it can be considered as a quite expensive act. And need of reactive power is minimal with these rectifiers, so power factor may become strongly capacitive and it may be a technical problem and in many cases tariffs may cause excessive bills for users. Active harmonic filtering is technically a better solution, but investment cost is considerably higher. Normal power factor correction is not possible even if necessary, if transformer secondary is used for electrical vehicle charging.

Rectifier properties

Simulations before have been calculated using typical rectifier that represents practically the worst case. If applying the other type that is much more close to sinusoidal character effect to power quality is much smaller. Future is unknown but using these two variations it may be concluded that using very basic type of rectifier, effects on power quality may be very serious and cause difficulties in power distribution and especially by consumers.

Conclusions

Number of electrical vehicles will increase greatly in the future. This will cause need of distribution network strengthening, but if using simple rectifiers when charging cars it may lead to serious problems in power distribution and for consumers. Solving this problem in distribution network is possible but expensive. If using more complicated rectifiers, these problems can be avoided to great degree. This is possible only if these requirements are considered in standards. Hence it is important that future standards in this area will handle these questions in the way problems will be avoided.

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